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Shear Behavior of Solid and Hollow Cylindrical Concrete Beams Made with Recycled Brick

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ABSTRACT

The impact of treated waste crushed brick on shear behavior regarding reinforced concrete beams (RCBs) has been the primary focus of the presented work. A total of 12 concrete beams of 240 mm in height, 1100mm in length, and 130mm in width were used for that purpose. A total of 3 Normal Concrete Beams (HNCB) and 3 Solid Normal Concrete Beams (SNCB) comprise 6 Normal Concrete Beams (NCB) models. In addition, there are 3 Hollow Recycled Brick Concrete Beams (HRBCB) and 3 Solid Recycled Brick Concrete Beams (SRBCB) among the 6 Recycled Brick Concrete Beams (RBCB) models. The obtained crushed brick from building demolition wastes is incorporated in the concrete mixes at these percentages of 0%, and 50% as a replacement by the weight of coarse aggregate. Samples have been tested for bending at four points. The maximum deflection happened at mid-span of the beam. In the test, diagonal cracking load, as well as ultimate shear strength, were assessed to examine the behavior of the beam concrete with the waste material. The purpose of this experiment has been to ascertain how crushed brick affected the mechanical characteristics of RCBs. Furthermore, the outcomes demonstrate that the addition of crushed brick enhanced the mechanical characteristics of samples and enhanced shear behavior regarding the concrete beams made of crushed brick in comparison to control samples. The findings contribute to the understanding of the mechanical behavior and failure mechanisms of such beams and provide valuable insights into the potential use of recycled brick aggregates in structural applications.

1. INTRODUCTION

After concrete, brick is regarded as the most widely utilized construction material. It is regarded as an environmentally favorable substitution to recycle brick waste when manufacturing concrete. This problem could be resolved by using waste materials, which are probably utilized in the concrete industry rather than being disposed of in landfills [1]. Recently, there has been a rise in interest in the use of such various waste ratio materials as substitutes for aggregate in producing new concrete [2-7]. Using recycled aggregates in construction and building projects is encouraged in several nations. Numerous studies have examined the benefits and downsides of using recycled aggregate to create new concrete [8-15]. Research has examined how the aggregate replacement ratio in concrete made from recycled clay bricks affects the mixture. Gonzalez-Corominas and Etxeberria [16] came to the conclusion that fine aggregate replacement with 30% recycled ceramic aggregates produced concrete with performance that was comparable to or slightly better than conventional concrete. In their study, González et al. [17] examined the replacement of natural fine as well as coarse aggregate in precast prestressed beams with ceramic brick aggregate. They discovered that structural concrete might have a replacement ratio of up to 35%. While this was happening, Gayarre et al. [18] investigated how the replacement of coarse as well as fine aggregates with recycled brick aggregates led to a noticeable rise in shrinkage, yet only minor differences in creep. It was determined that it was possible to utilize the recycled brick aggregates in concrete for structural applications at a replacement ratio of up to 20%. In their investigation into the impact of varying clay brick substitutions (20%, 50%, and 100%) as well as ceramic aggregates on concrete durability, Vieira et al. [19] found that while carbonation, shrinkage, and water absorption were negatively impacted, water sorptivity and chloride ion penetration enhanced with the increase of replacement ratios. Because of the porous micro-structure and poor mechanical characteristics of clay brick aggregate, the porosity regarding concrete increased as well as the mechanical performance decreased [20, 21]. The durability, particularly concrete permeability, gradually decreased as the replacement level increased. In the case when RC beams produced with recycled brick aggregates are to be utilized securely, more research is still required to determine whether ACI-318 rules may be applied [22]. With this background, this study was planned. The manuscript presents a well-designed experimental study on the shear behavior of solid and hollow concrete beams made with recycled brick aggregates. Which aligns well with current sustainability efforts in construction. Twelve RC beams were made with different steel ratios and different types of aggregates including virgin and recycled brick aggregates. The beams were tested under two-point loading. Cracking moment, ultimate moment, and failure pattern were recorded for comparison with the virgin brick aggregates.

2. EXPERIMENTAL PROGRAM

2.1 Material properties

The raw materials employed in the presented work are Cement: Recycled Portland Cement; Normal Sand - Coarse Aggregate (NG); Natural Sand - Fine Aggregate (NS); and Recycled Brick Aggregate (BG), as illustrated in Figure 1; All forms of aggregates have their physical and mechanical qualities compiled in Table 1. In this study, Reinforcing Bars-ribbed longitudinal steel bars with nominal diameters of 12mm, 16mm, and 6mm are utilized. Table 2 lists the mechanical characteristics of steel bars in terms of maximum elongation, average yield tensile strength, and ultimate tensile strength. Plastic pipe: Plastic was utilized in pipes. For hollow concrete beams, as can be seen in Figure 2, a diameter of 6 cm is used throughout the whole beam. Mixing Water: All beam specimens are cast and cured using tap water.

Figure 1. Recycled brick aggregate waste

Table 1. Physical and mechanical characteristics of all aggregate types

Samples	Grading	Samples	Grading	Samples
Natural sand	0–5	2.64	1.14	1681
Natural gravel	5–14	6.68	0.88	1672
Recycled Brick	5–14	2.08	5.84	970

Table 2. Steel bar mechanical characteristics

Diameter (Steel Bar) mm	Bar Type	Yield Strength (fy) MPa	Ultimate Strength (fu) MPa	Max. Elongation (%)
6	Round	453	483	30
12	Ribbed	642	747	21
16	Ribbed	531	635	19

2.2 Mix design

Table 3 lists the concrete mix by weight for Group 1 and Group 2.

2.3 Moulds and specimens description

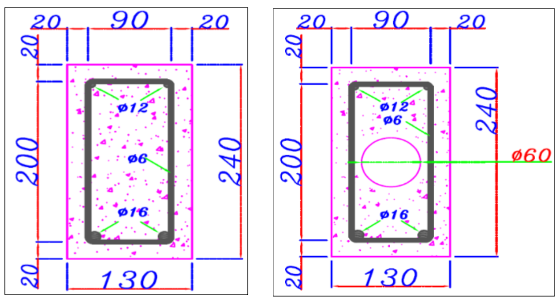
A total of 12 concrete beams with a width of 130mm, height of 240mm, and length of 1100mm were utilized as the cement, and the transverse reinforcement spaces were consistently equal. The Specimens details of the models used in this study were according to ACI-318 rules and are very important as a starting point for future research and studies.

The ratio of length, width, and height, as well as the calculation of the ratio of reinforcing steel, were within the limits of the specification. A total of 6 NCB models have been prepared, such as 3 SNCB without the hollow and the remaining 3 HNCB with poured Hollow Low Diameter of 6 cm across all 110 cm beams. A total of 6 other models of RBCBs have been prepared; they included 3 HRBCB and 3 SRBCB without the hollow. All measurements are in millimeters, and the cross-sectional features of such specimens are displayed in Figure 3. Normal concrete had an average cube compressive strength (fcu) of 39MPa, while lightweight concrete had a fcu of 24. All beams underwent longitudinal reinforcement top and down to be deformed into steel reinforcing bars with diameters of 12mm and 16mm. Additionally, as it has been depicted in Figure 4 and Figure 5, a reinforcing bar with vertical stirrups that have a diameter of 6 mm was arranged at 50, 13, and 6 cm intervals. All of the dimensions are in millimeters.

Figure 2. Reinforcing bars and pipe plastic

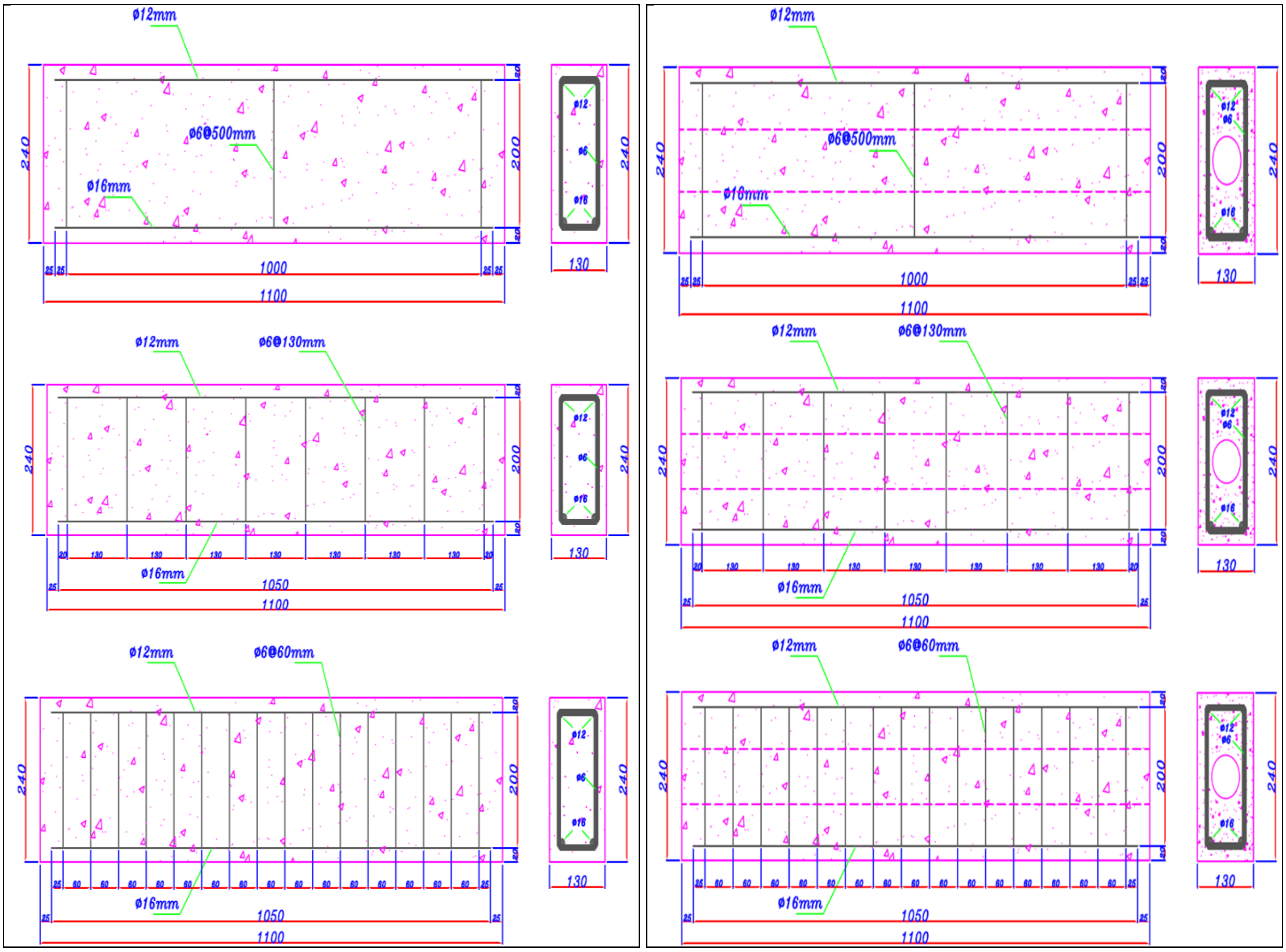
Table 3. Proportions of the mix by weight

Mix No.		Group 1	Group 2
Portland Cement (C), (kg/m^3)		420	420
Fine sand (F.S) (kg/m^3)		630	630
Coarse Aggregate (kg/m^3)		1000	480
Recycled Brick Waste (kg/m^3)	Sand Replacement of Recycled Brick (%) by weight	0%	50%
	Recycled Brick	0	520
Water (w) (kg/m^3)		200	200



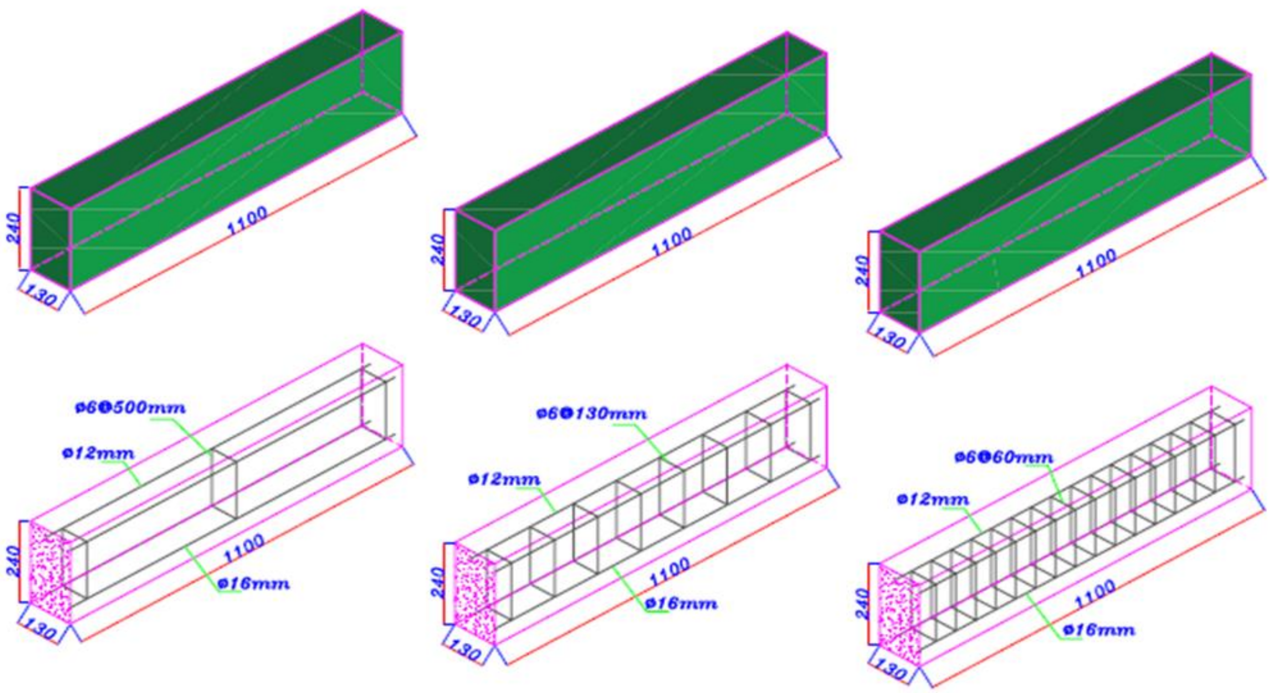
(a). Solid concrete beam (b). Hollow concrete beam

Figure 3. Beam sectional details [cross section]

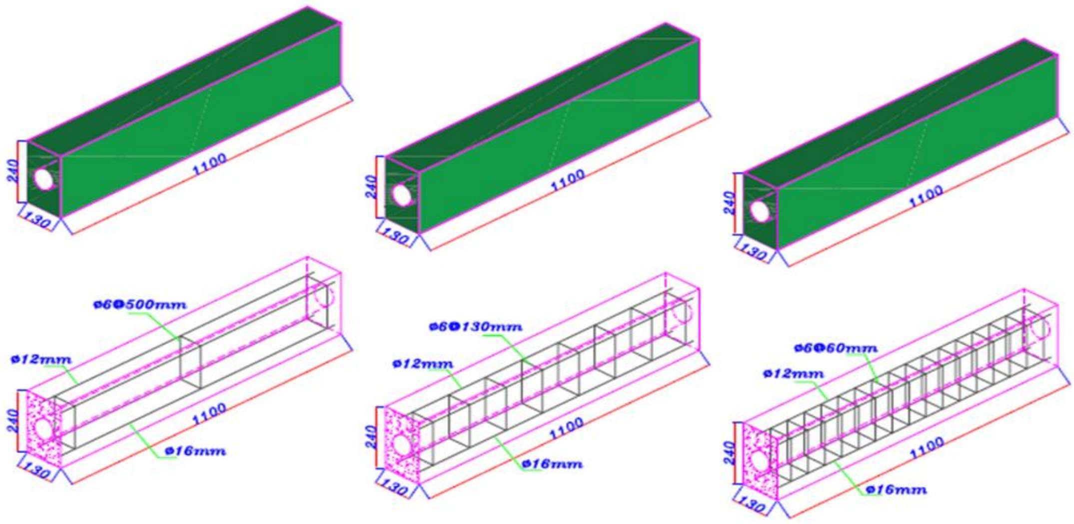


(a). Solid concrete beam (b). Hollow concrete beam

Figure 4. Elevation details of beam [cross section] (2D)



a. Solid concrete beam



b. Hollow concrete beam

Figure 5. Elevation details of beam [cross section] (3D)

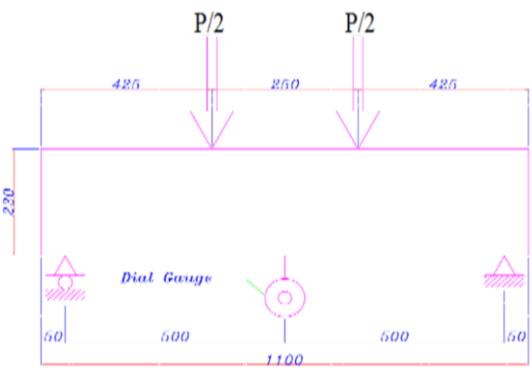
2.4 Specimen preparation (Casting, mixing, compacting, and curing procedure)

Every specimen was prepared in the laboratory. For the casting of all HNCB, SNCB, SRBCB, and HRBCB, mixed concrete was used. Beams have been taken out of the tank containing curing water after a day, precisely 28 days later. In order to determine compressive strength, cube concrete specimens (15×15 cm) were also cast, as shown in Figure 6.

Figure 6. SNCB, HNCB, HRBCB, and SRBCB out of water

3. TEST SETUP AND INSTRUMENTATION DETAILS

One dial gauge (ELE type) represents the structural responses of the HNCB, SNCB, SRBCB, and HRBCB. As shown in Figure 7, it has been positioned below Beams at the midpoint to confirm the downward deflection.



a) Side view of the beam

b) Universal testing machine (MFL system)

Figure 7. Test instrumentation

4. RESULTS OF THE ANALYSIS

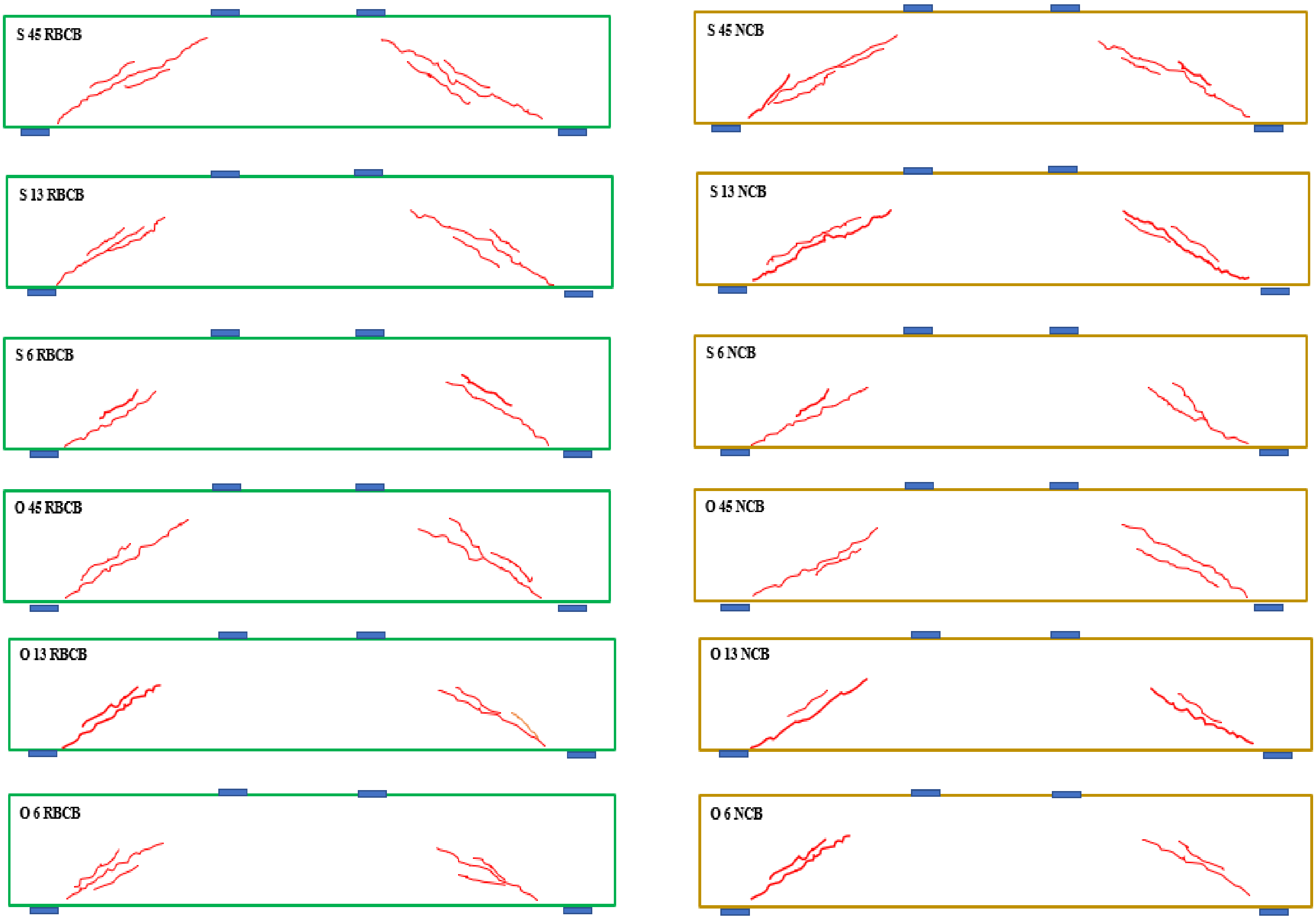
A total of 12 examples of RCBs have been studied in this paper. RCB has the same measurements for width, thickness, and length. As web reinforcement, several steel stirrup bars with diameters of 6 mm have been prepared at distances of 450 mm, 130 mm, and 60 mm. A total of 3 SRRCB without a hollow are present in 6 RCB models (S 13 RBCB, S 45 RBCB, S 6 RBCB). Along the 1000 mm al beam, the 3 additional HRRCB poured cavities measuring 50 by 75 mm (O 13 RBCB, O 45 RBCB, and O 6 RBCB). Furthermore, reinforcement. Three SNCB (S 13 NCB, S 45 NCB, and S 6 NCB) without a hollow are present in 6 RCB models. The three extra HNCB (O 13 NCB, O 45 NCB, and O 6 NCB) poured cavities measuring 50 by 75 mm along the 1000 mm al beam).

4.1 Mechanical characteristics (First crack loads, crack patterns, ultimate loads)

Table 4 displays the results of the cracking as well as load-carry level capacity tests. The SRBCB and HRBCB specimens were subjected to Load Level (kN) (Experimental) carry capacity; at around 17.6-28.4% of Load Level (kN) (Experimental) carry capacity for RCB, the first cracks appeared. Additionally, roughly 17.9–29.3% of Load Level (kN) (Experimental) carry capacity for RCB is also present for HNCB and SNCB. A total of 3 SRBCB models (S 13 RBCB, S 45 RBCB, and S 6 RBCB) without a hollow are included in the RCB models. The first crack load (Pcr) values are (17.6, 22.50, and 17.8) kN. The three more HRBCBs are O 13 RBCB, O 45 RBCB, and O 6 RBCB, and their respective kN values are (16.5, 14, and 18.5). The first crack load (Pcr) for the 3 SNCB models (S 13 NCB, S 45 NCB, and S 6 NCB) without a hollow are 17.5, 16.5, and 18.5 kN in the RCB models. The 3 extra HNCB are (19, 17, and 21) kN, respectively (O 13 RBCB, O 45 RBCB, and O 6 RBCB). A total of 3 SRBCB (S 13 RBCB, S 45 RBCB, S 6 RBCB) had Ultimate Load Level (Pu) values of (78, 60, and 87) kN, while 3 HRBCB (O 13 RBCB, O 45 RBCB, and O 6 RBCB) had values of (58, 49, and 69) kN. A total of 3 SNCB (S 13 NCB, S 45 NCB, S 6 NCB) had Ultimate Load Level (Pu) values of (90, 75, and 103) kN, while three HNCB (O 13 NCB, O 45 NCB, O 6 NCB) had Ultimate Load Level (Pu) values of (73, 58, and 81) kN. A total of 3 SRBCB (S 13 RBCB, S 45 RBCB, S 6 RBCB) and 3 HRBCB (O 13 RBCB, O 45 RBCB, O 6 RBCB) RCB models show shear cracks that occur after the steel reinforcement yields and ultimate crushing of RCB in the zone of compression (Figure 8). Comparing all of such RBCB test results to the six NCBs of normal weight, the difference was less than 17%. This enhances the accuracy of the results as hollow beam models are weaker or less tolerant of forces with solid beams due to the poured hollow Cylindrical diameter extending along the concrete beam.

Table 4. First crack and ultimate loads (SNCB, HNCB, HRBCB, & SRBCB)

Name of the Group	Beam Designation	f_{cu} (MPa)	First Crack Load (P_{cr}) (kN)	Ultimate Load (P_u) (kN)	$\frac{P_{cr}}{P_u}$ (%)
Solid Normal Concrete Beams (SNCB)	S 45 NCB	39.0	16.5	75	22.0
	S 13 NCB	38.5	17.5	90	19.4
	S 6 NCB	39.5	18.5	103	17.9
Hollow Normal Concrete Beams (HNCB)	O 45 NCB	40.0	17	58	29.3
	O 13 NCB	38.5	19	73	26.7
	O 6 NCB	39.0	21	81	25.9
Recycled Brick Concrete Beam (SRBCB)	S 45 RBCB	23.5	13.5	60	22.5
	S 13 RBCB	24.0	14.5	78	17.6
	S 6 RBCB	24.5	15.5	87	17.8
Hollow Recycled Brick Concrete Beams (HRBCB)	O 45 RBCB	23.0	14.0	49	28.5
	O 13 RBCB	23.5	16.5	58	28.4
	O 6 RBCB	24.0	18.5	69	26.8



a. Crack patterns at ultimate failure (SRBCB & HRBCB) **b.** Crack patterns at ultimate failure (SNCB & HNCB)

Figure 8. Crack patterns

4.2 Ultimate loads

The Load Levels for HRBCB (O 13 RBCB, O 45 RBCB, and O 6 RBCB) have been less strong than the Ultimate Load Levels for SRBCB (S 13 RBCB, S 45 RBCB, and S 6 RBCB), as shown in Figure 9 and Table 5's test results. Figures 10 and 11 illustrate the comparison between NCB and RBCB. As seen in Figures 12 and 13, the load-carry level capacity for all beams (HRBCB & SRBCB) rises with the distance of vertical stirrups bar reinforcement (6mm diameter). As may be seen from Figures 14-15, NCB and RBCB comparison. Solid beams' (S 13 RBCB, S 45 RBCB, S 6 RBCB) decline in load-carry level capacity is around (20%) less than that of hollow beams' (O 13 RBCB, O 45 RBCB, O 6 RBCB) average load level capacity.

Table 5. The value of deflection at first crack and ultimate load values (SNCB, HNCB, HRBCB, and SRBCB)

Group Name	Designation of Beam	Deflection at 1st Crack (mm)	Deflection at Ultimate Load (mm)
Solid Normal Concrete Beams (SNCB)	S45 NCB	0.07	1.15
	S 13 NCB	0.09	1.37
	S 6 NCB	0.10	2.01
Hollow Normal Concrete Beams (HNCB)	O 45 NCB	0.09	0.63
	O 13 NCB	0.12	2.14
	O 6 NCB	0.14	2.05
Recycled Brick Concrete Beam (SRBCB)	S 45 RBCB	0.10	2.01
	S 13 RBCB	0.12	2.37
	S 6 RBCB	0.13	2.68
Hollow Recycled Brick Concrete Beams (HRBCB)	O 45 RBCB	0.12	1.82
	O 13 RBCB	0.17	2.51
	O 6 RBCB	0.19	3.17

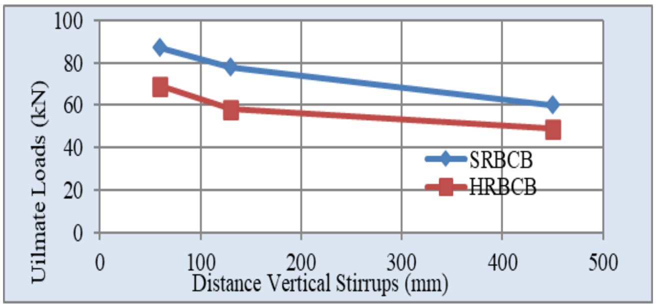


Figure 9. Ultimate load-distance vertical stirrups bar reinforcement (6 cm, 13 cm, 45 cm) relationships for SRBCB & HRBCB

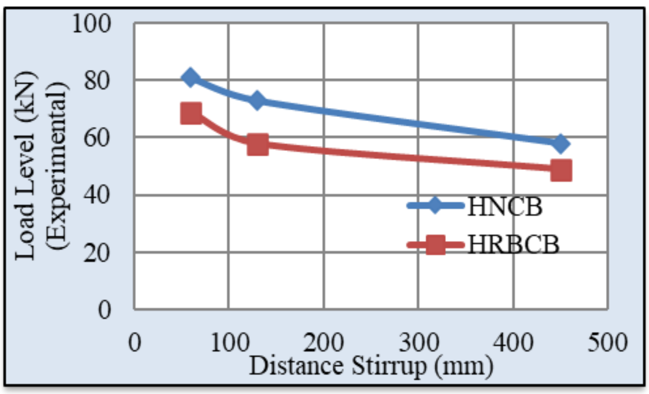


Figure 10. Ultimate load-distance vertical stirrups bar relationships for HRBCB and HNCB

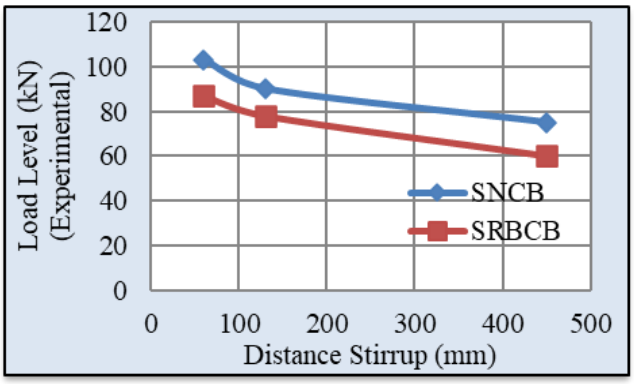


Figure 11. Ultimate load-distance vertical stirrups bar relationships for SRBCB and SNCB

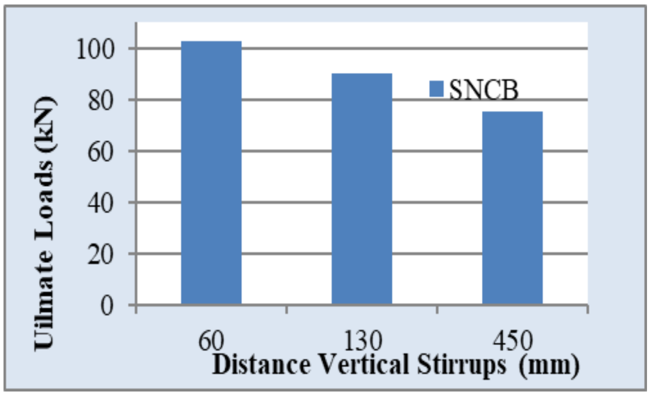


Figure 12. Ultimate load-distance vertical stirrups bar reinforcement relationships with SNCB

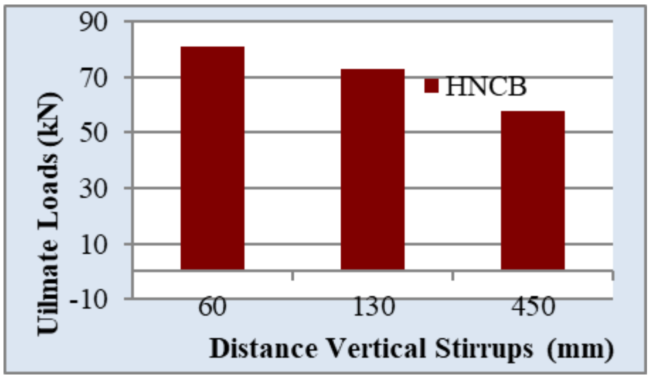


Figure 13. Ultimate load-distance vertical stirrups bar reinforcement relationships with HNCB

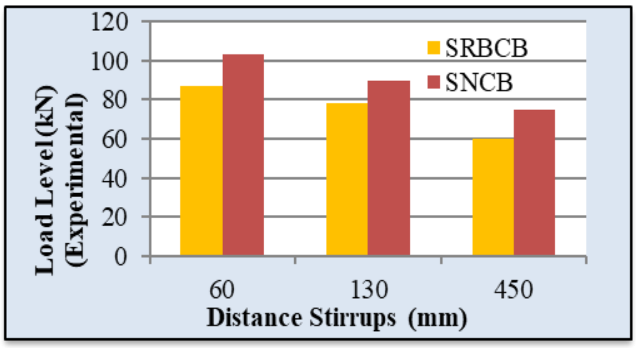


Figure 14. Ultimate load-distance vertical stirrups bar reinforcement relationships with SRBCB & SNCB

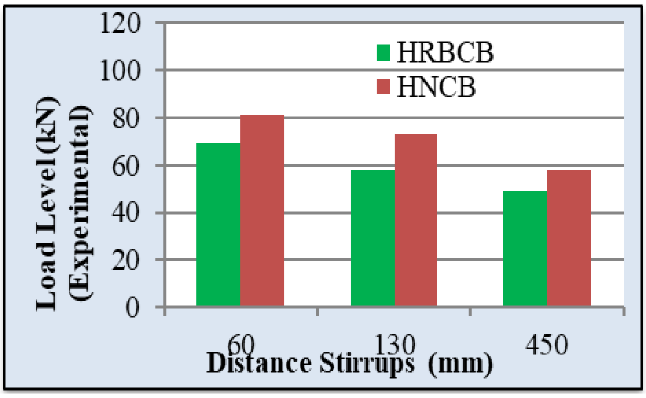


Figure 15. Ultimate load-distance vertical stirrups bar reinforcement relationships with HRBCB & HNCB

4.3 Load-deflection relations

Table 5 displays deflection experimental findings for the HNCB, SNCB, HRBCB, and SRBCB beams. According to the findings of the experimental tests, the SNCB and SRBCB beams exhibit a maximum deflection at the ultimate load of 6 cm in the case when the distance between vertical stirrups bar reinforcement (6mm diameter) is 45cm, which is comparable to the HRBCB and HNCB beams. Load-deflection relationships for beams (HNCB and SNCB beams) are displayed in Figure 16 and Figure 17. A comparison of normal-weight and lightweight concrete beams is displayed in Figures 18 to 23.

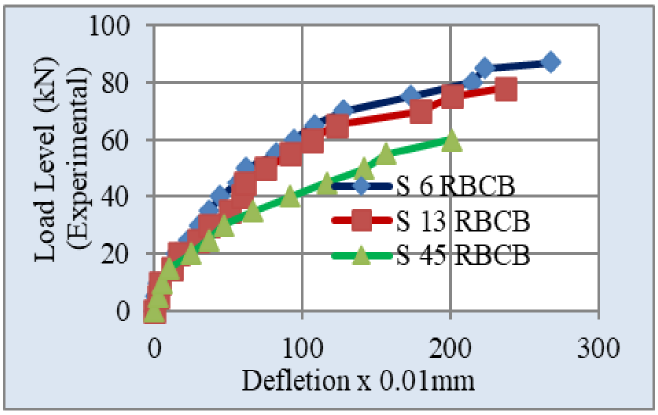


Figure 16. Load-deflection relations for SRBCB (S6, S13, S45)

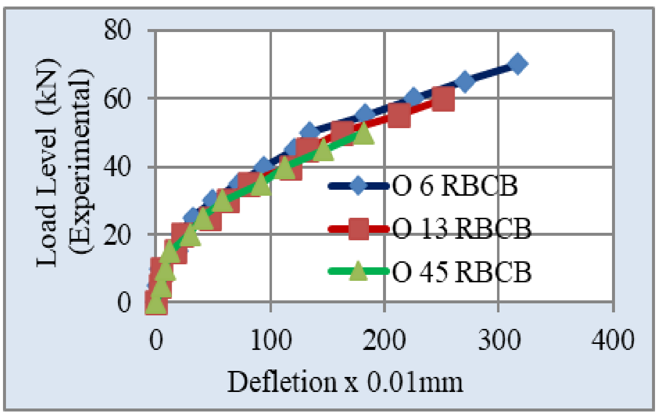


Figure 17. Load-deflection relations for HRBCB (O6, O13, O45)

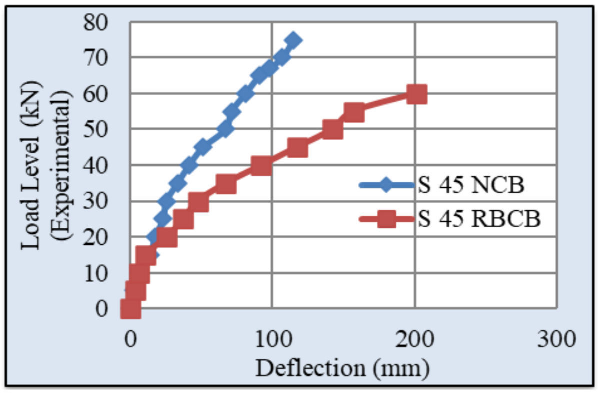


Figure 18. Load-deflection relationships for SNCB and SRBCB (S 45)

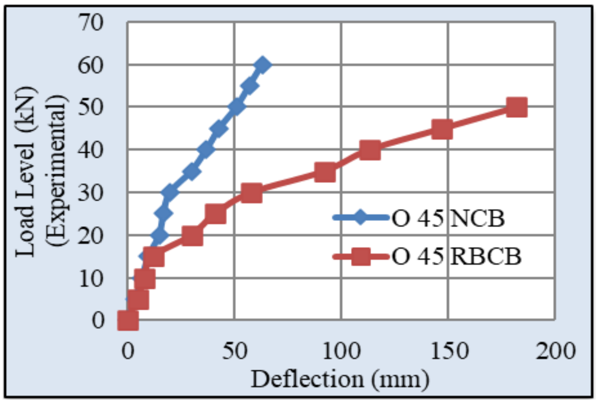


Figure 19. Load-deflection relationships for HNCB and HRBCB (O45)

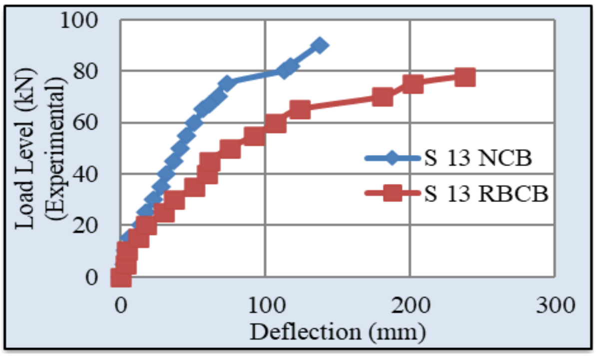


Figure 20. Load-deflection relationships for SNCB and SRBCB (S 13)

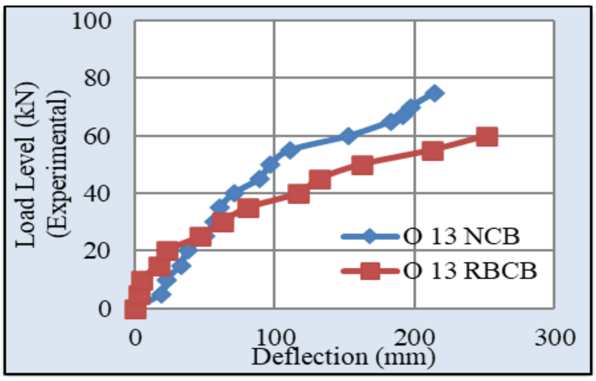


Figure 21. Load-deflection relationships for HNCB and HRBCB (O 13)

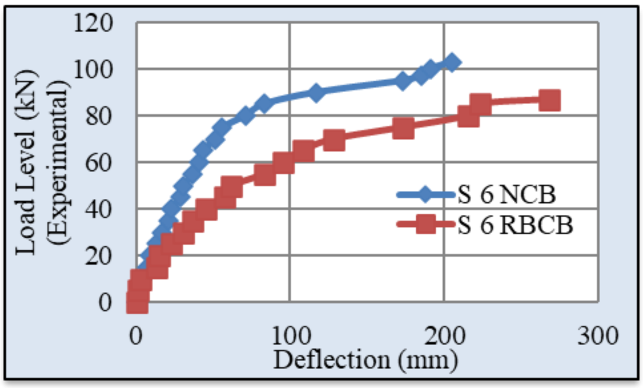


Figure 22. Load-deflection relationships for SNCB and SRBCB (S6)

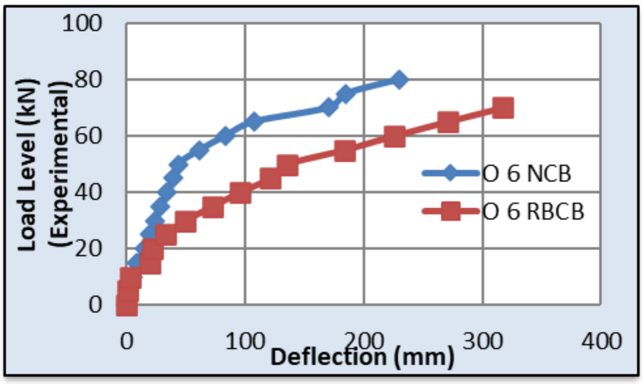


Figure 23. Load-deflection relationships for HNCB and HRBCB (O6)

5. CONCLUSIONS

Experimental examination results on the reinforced HRBCB are presented in the present study. A total of 6 reinforced lightweight concrete beams in all have been built and put through testing using a two-point bending technique. Configuration and size of the reinforced HRBCB beams were research parameters. The reinforced SRBCB with the hollow section removed is compared to see which has the higher ultimate deformation capacity. The main topic of discussion for the shear resistance mechanism regarding SRBCB beams and HRBCB beams is the deterioration of concrete shear resistance. The following findings are reached based on test observations:

1- With respect to the midspan deflection of 2.51, 1.82, and 3.17 mm and an ultimate load of 58, 49, and 69 kN, the specifics of the failed beam are represented by the HRBCB. The ultimate failure has been mostly caused by concrete crushing at the zone of compression, and the load vs. deflection response has been pure flexural.

2- Testing results have further demonstrated that load-carrying capacity and mid-span deflection of the hollow HLC beams were not significantly affected by the hollow opening configuration.

3- Not every HRBCB showed evidence of longitudinal steel bars in tension or compression yielding. Nonetheless, in every HRBCB beam, tensile or compressive yielding of the vertical stirrups was noted. This is evidence of the failure of HRBCB beams in shearing cracks.

4- In the case when vertical stirrups bar reinforcement distance is at its minimum, the maximum deflection of SRBCB and HRBCB occurs at the ultimate load.

5- The ultimate weights for all SRBCB and HRBCB are reduced by distance vertical stirrups bar reinforcement (diameter of 6 mm).

Therefore, the use of recycled brick aggregates in structural concrete production applications reinforces the right approach to continue conducting more research to demonstrate the urgent need to reduce the brick waste that we as humans still suffer from its spread in our world. Because of the ongoing limitations, more research in this field is necessary. Additional research ought to focus on the building's slabs and columns.

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NOMENCLATURE

HNCB	Hollow Normal Concrete Beams
SNCB	Solid Normal Concrete Beams
NCB	Normal Concrete Beams
HRBCB	Hollow Recycled Brick Concrete Beams
SRBCB	Solid Recycled Brick Concrete Beams
RBCB	Recycled Brick Concrete Beams
NG	Coarse Aggregate
NS	Fine Aggregate
BG	Recycled Brick Aggregate